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TOWARD A PROGRAM OF RESEARCH ON KNOWLEDGE FLOW IN THE VERY-LARGE ENTERPRISE

by

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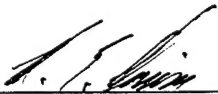
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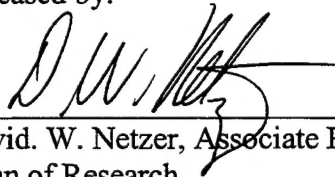
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Knowledge is power. As the U.S. Navy is working to revise its strategy and tactics through knowledge-centric warfare, it is apparent that *knowledge flow* is key. However, our current state of understanding does not address the phenomenology of knowledge flow well, nor do we have the benefit of knowledge-flow theory and its application to very-large enterprises such as the Navy. Without such basic understanding, one cannot expect to design effective systems and processes for network-centric warfare. The basic research program proposed here addresses this deficiency directly through its three-pronged technical approach: 1) develop and refine a model of knowledge-flow theory, emphasizing the very-large enterprise (e.g., Navy, Department of Defense); 2) develop a contingency model for matching the most-appropriate process and system designs to enterprise knowledge-flow patterns; 3) assess the performance effects of alternative knowledge systems and processes through simulation (e.g., of naval warfare, personnel processes). Informed by the basic science of knowledge-flow theory, this work can propel knowledge management toward the methods and tools commonly used for engineering work—a quantum shift from the current state of affairs. This, basic research also directly supports ongoing, priority ONR projects (e.g., Sailor-21, advanced command and control, artificially-intelligent systems and decision aids) and should contribute to development of network-centric warfare concepts, systems and operations.

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Motivation

Knowledge is power. This saying has long been ascribed to successful individuals in the organization, but today it is recognized and pursued at the enterprise level through a practice known as knowledge management [12]. Although knowledge management has been investigated in the context of decision support systems and expert systems for over a decade [56], interest in and attention to this topic have exploded recently. For example, many prominent technology firms now depend upon knowledge-work processes to compete through innovation more than production and service [34], and Drucker [17, p. 271] writes, "knowledge has become the key economic resource and the dominant—and perhaps even the only—source of comparative advantage." This follows his assertion that increasing knowledge-work productivity represents the great management task of this century, on par with the innovation and productivity improvements made through industrialization of manual-work processes [16]. Brown and Duguid [3, p. 90] add, "organizational knowledge provides synergistic advantage not replicable in the marketplace." Indeed, some forecasts suggest knowledge work will account for nearly 25% of the workforce in the early 21st century [27]. And partly in anticipation, fully 40% of Fortune-1000 companies have established the role of Chief Knowledge Officer (CKO) in their companies [51].

The U.S. Navy has also appointed a CKO, and the leadership is working to revise its strategy and tactics around knowledge through a new emphasis on network-centric warfare [14]. With this new thinking, the *knowledge warrior* concept is now being developed [26] along with the *network-centric organization* [15], albeit with minimal science or theoretical foundation involved or available for guidance. Network-centric warfare represents relatively-new military thinking, but there is already a realization in the Navy that simply connecting sensors, weapons, databases and people through a network is not enough. Rather, knowledge possessed by warfighters provides the basis for sustainable competitive advantage, and such knowledge requires effective organization and rapid, dispersed distribution.

With this, it is apparent that *knowledge flow* is critical to current and future naval warfare. However, most current discussions and publications along these lines pertain to the emerging practice of *knowledge management*—a (justifiable) fad to many—which is filled with hyperbole and unfounded vendor claims. Indeed, surveying the current state of the practice in knowledge management [39, 43], it is principally limited to consulting unguided by theory, building systems by trial and error, and experimenting with groupware applications without scientific basis. Indeed, our current state of understanding does not address the phenomenology of knowledge flow well, nor do we have the benefit of knowledge-flow theory and its application to very-large enterprises such as the Navy. In contrast to relatively-good, current understanding of data flow and information flow, negligible science addresses *knowledge flow*, which is distinctively different and more complex.

Without basic research to develop knowledge and understanding of this phenomenon, current and future attempts to design and build effective systems and processes for automation and support of knowledge flow will remain relegated to the kind of unguided, trial-and-error practice observed at present. This current situation is far from the desired state of *engineering* such knowledge systems and processes. Therefore, given the current state of the art and knowledge in this area, *basic research* is required to understand and model the underlying phenomenology of knowledge flow. And given the mission and context of the Navy, understanding such phenomenology in the geographically-distributed environment of a very-large enterprise is particularly important. Such understanding does not exist today.

The proposed program of research addresses this basic research challenge directly, and it seeks to specifically understand knowledge flow in the Navy. This proposed, basic research also supports the Navy's Sailor-21 program—directly addressing knowledge flow necessary for such core processes as selection and classification, distribution and assignment, and knowledge system development—as well as supporting Mathematical, Computer and Information System Division work on command and control and artificially-intelligent systems and decision aids. **The proposed research is thus basic, important, Navy-related and supportive of current, priority ONR projects.**

Research Objective and Questions

The primary objective of this proposed research program is to develop scientific knowledge and understanding (i.e., theory) pertaining to the phenomenon of knowledge flow. In the context of network-centric warfare, good theory [1]—that can *describe* a variety of knowledge systems and processes, *explain* why certain practices and systems are successful while others are not, and *predict* which organizational and technological interventions offer the greatest likelihood of performance improvement—should be very useful to the Navy leadership and help advance science and understanding pertaining to knowledge and its flow through the very-large enterprise.

This objective leads to three principal research questions.

1. What theoretical model can describe, explain and predict knowledge flow?
2. How can knowledge-flow theory be applied to inform the design of systems and processes in very-large enterprises?
3. What impact on enterprise performance can knowledge-flow systems and processes effect?

Relation to the Present State of Knowledge

This section summarizes key background work pertaining to knowledge flow. The section begins by drawing from the emerging knowledge management literature itself. The seminal research to integrate knowledge process and system design is then covered. Early results from some Navy-specific, follow-on research projects follow, after which we outline the most-advanced theoretical underpinnings published to date concerning knowledge flow. This leads directly to the three-pronged technical approach proposed for the present investigation.

Knowledge Management Literature

As noted above, the emerging phenomenon of knowledge management is generating substantial attention. Miles et al. [35, p. 281] caution, however, "knowledge, despite its increasing abundance, may elude managerial approaches created in 20th century mindsets and methods." In fact, knowledge is proving difficult to manage, and knowledge work has been stubbornly resistant to reengineering and process innovation [9]. For one thing, Nonaka [47] describes knowledge-creation as primarily an individual activity, performed by knowledge workers that are mostly professional, well-educated and relatively autonomous, often with substantial responsibility in the organization. They tend to seek and value their relative autonomy and often resist perceived interference by management in knowledge-work activities [10]. Moreover, substantial, important knowledge is tacit, unstructured [47] and external to the organization [19]. This can greatly impede the identification, acquisition, interpretation and application of such knowledge. Also, corporate knowledge has historically been stored on paper and in the minds of people [48]. Paper is notoriously difficult to access in quantity and keep current on a distributed basis, and knowledge kept in the minds of workers is vulnerable to loss through employee turnover and attrition. Vulnerability to such loss of knowledge is exacerbated by recent waves of downsizing associated with reengineering [34], post-Cold-War military force restructuring and the constrained labor markets affecting many professions (esp. information technology and software engineering). Four, important segments of the knowledge management literature are summarized below and related to current Navy practice: 1) knowledge hierarchy, 2) extant information technology, 3) knowledge-based systems, and 4) business process reengineering.

Knowledge Hierarchy. Consistent with current Navy practice, most information technology (IT) employed to enable knowledge work, in general, appears to target data and information, as opposed to knowledge itself [53]. This contributes to difficulties experienced with knowledge management to date. Knowledge, almost by definition, lies at the center of knowledge work, yet it is noted as being quite distinct from data and information [11, 47, 58]. Indeed, many scholars [12, 43, 62] conceptualize a hierarchy of knowledge, information and data. As illustrated in Figure 1, each level of the hierarchy builds on the one below. For instance, data are required to produce information, but information involves more than just data (e.g., need to have the data in context). Similarly, information is required to produce knowledge, but

knowledge involves more than just information (e.g., it enables action). We have notionally operationalized the triangular shape of this hierarchy using two dimensions—abundance and actionability—to further differentiate between the three constructs.

Briefly, data lies at the bottom level, with information in the middle and knowledge at the top. The broad base of the triangle reflects the abundance of data, with exponentially less information available than data and even fewer chunks of knowledge in any particular domain. Thus, the width of the triangle at each level reflects decreasing abundance as one progresses from data to knowledge. The height of the triangle at each level reflects actionability (i.e., one's ability to take appropriate action). Converse to their abundance, data are not particularly powerful for supporting action, and information is more powerful than data. But knowledge supports action directly, hence its position at the top of the triangle. This, notional view of the hierarchy is shared by many scholars. We return to refine this multi-level conceptualization of knowledge, information and data as part of our technical approach.

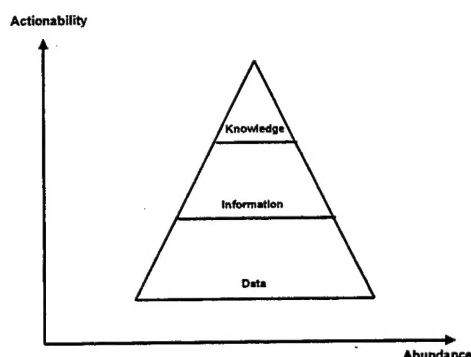


Figure 1 Knowledge Hierarchy

Extant Information Technology. Also consistent with current Navy practice, extant IT used to support knowledge management, in general, is limited primarily to conventional database management systems (DBMS), data warehouses and mining tools (DW/DM), intranets/extranets, portals and groupware [48]. Arguably, just looking at the word "data" in the names of many "knowledge management tools" (e.g., DBMS, DW/DM), we are not even working at the level of information, much less knowledge. And although (esp. Web-based) Internet tools applied within and between organizations provide a common, machine-independent medium for the distribution and linkage of multimedia documents, extant intranet and extranet applications focus principally on the management and distribution of information, not knowledge per se. Although a great improvement over previous stove-piped systems, islands of automation and other information systems maladies, as Nonaka [47, p. 15] states, such "information is [just] a flow of messages," not knowledge.

Along these same lines, groupware offers infrastructural support for knowledge work and enhances the environment in which knowledge artifacts are created and managed, but the management of knowledge itself remains indirect. For instance, groupware is widely noted as helpful in the virtual office environment (e.g., when geographically-dispersed knowledge workers must collaborate remotely) and provides networked tools such as shared, indexed and replicated document databases and discussion threads (e.g., Lotus Notes applications), as well as shared "white boards," joint document editing capabilities and full-duplex, multimedia communication features. These tools serve to mitigate collaborative losses that can arise when rich, face-to-face joint work is not practical or feasible. But the knowledge itself remains tacit and "one off" from direct application with these tools, as a *person* is still required to identify, acquire, interpret and use the knowledge artifacts and services supported by groupware. Nonetheless, these are the kinds of systems and practices presently being applied—albeit in trial-and-error fashion—through current knowledge management projects.

Knowledge-Based Systems. In contrast to current Navy practice, construction and employment of knowledge-based systems (KBS), in general, can make knowledge explicit and its application direct. Key KBS technologies include applications such as expert systems and intelligent agents, along with infrastructure and support tools such as ontologies, knowledgebases, inference engines, search algorithms, list and logic programming languages and a variety of representational formalisms (e.g., rules, frames, scripts, cases, models, semantic networks). Much deeper than just their names' sake, KBS are predicated on the capture, formalization and application of strong domain knowledge, and use of KBS for knowledge organization and distribution is well known and widespread.

Unlike the extant IT tools noted above, the substance of KBS is knowledge itself—not just information or data—and KBS are designed to identify, acquire, interpret and apply represented knowledge directly. These capabilities and features make KBS distinct from the classes of extant IT applications presently employed for knowledge management, yet KBS also offer good potential to complement existing tools by changing the manner in which knowledge-work itself is accomplished; that is, by directly addressing knowledge as such, KBS are proving useful as IT enablers to innovate knowledge-work processes. As an example, Nissen [39] demonstrates how an expert system developed to automate and support key, knowledge-work activities associated with process redesign is used to effectively formalize, distribute and apply critical knowledge in an "industrial strength" naval-process setting.

Moreover, almost by definition, expert system development—through classic knowledge engineering—includes explicit capture and formalization of tacit knowledge possessed by experts. This is just the kind of tacit knowledge researchers [31, p. 112] stress "underlies many competitive capabilities," suggesting one promising approach to a critical knowledge source they state is "hard to capture."

Business Process Reengineering. Also contrasting with current Navy practice, researchers emphasize the need to capture such knowledge is particularly important "in the wake of aggressive downsizing." This represents an indirect reference to the dramatic cost and staff reductions stemming from business process reengineering (BPR), and it applies directly to military force restructuring that took place during the Nineties. Indeed, substantial integration of knowledge management with reengineering and restructuring has been observed, in general, in current practice, as companies begin to realize the direct connection between knowledge management and knowledge-work process innovation [11]. In their study of more than thirty knowledge management efforts in industry, Davenport et al. [10] note the practice is "fundamentally change management projects." Even emerging theory of knowledge creation and management has a dynamic, distinctly process-oriented flavor (see esp. [47]). Ruggles [54] goes so far as to suggest a primary objective of the practice is to assess the impact of knowledge management as a process, fundamentally a proposition of reengineering [23] and process innovation [8].

However, as learned through the painful, expensive and failure-prone "first wave" of reengineering [7], simply inserting IT into a process in no way guarantees performance improvement. Indeed, many otherwise successful and effective firms experienced process *degradation* as the result of reengineering [5, 23]. This point is underscored by Hammer [22], whom colorfully refers to such practice as "paving the cowpaths" and "automating the mess" (e.g., making a broken process simply operate, broken, faster). Drawing all the way back to Leavitt [29] and others [8, 38], new IT needs to be integrated with the design of the *process* it supports, which includes consideration of the organization, people, procedures, culture and other key factors, in addition to technology. Until the work of Nissen et al. [43], such integration of information system design with knowledge process design had been strangely missing from the knowledge management literature and practice.

Integrated Knowledge System and Process Design

Nissen, Kamel and Sengupta completed groundbreaking research that resulted in the seminal journal article to address how information system design can be integrated with knowledge process design [43]. The associated framework was subsequently published as a chapter in a widely-distributed book on knowledge management and virtual organizations [44] and as a strategic-management article in an information system executive publication [45]. It was also presented at a Stanford workshop [40], and it has been used to guide specific application to the maritime interdiction process [42], in addition to the follow-on research projects outlined in a subsequent section below. Three key elements of this integrative

framework are presented here: 1) knowledge management feature space, 2) coverage of extant systems and practices, and 3) integrated knowledge process and system design.

Knowledge Management Feature Space. In the literature, one can begin to observe a sense of process flow or a life cycle associated with knowledge management. Although the knowledge management life cycle is generally described as a sequence of activities, in practice the performance is quite iterative, as each activity is often revisited multiple times. Building upon this notion in Table 1, we outline key elements of several life cycle models drawn from the recent knowledge management literature (e.g., [12, 13, 20, 39]) to develop an amalgamated, general knowledge management process model. The Amalgamated Model integrates key concepts and terms from these four life cycle models and establishes a useful dimension for describing and characterizing knowledge activities at various stages.

Table 1 Knowledge Management Life Cycle Models

(Adapted from [43])

Model	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Nissen	Capture	Organize	Formalize	Distribute	Apply	
Despres and Chauvel	Create	Map/bundle	Store	Share/transfer	Reuse	Evolve
Gartner Group	Create	Organize	Capture	Access	Use	
Davenport & Prusak	Generate		Codify	Transfer		
Amalgamated	Create	Organize	Formalize	Distribute	Apply	Evolve

A second descriptive dimension is termed *knowledge management level*, and it can be operationalized in terms of the *reach* associated with some quantity of knowledge (e.g., knowledge chunk, knowledgebase, body of knowledge) through an enterprise. This concept draws from Nonaka [47] and others (e.g., [13]). The reach dimension extends from a single person, through work groups, to an enterprise as a whole and even across enterprises. Combined with the life cycle steps from above, inclusion of *reach* as a second dimension helps form a feature space that is useful for examining the coverage of extant systems and practices in the enterprise.

Table 2 Distribution of KM Systems and Practices

Phase	Enterprise	Organization	Individual
K Creation			
K Organization	X	X	X
K Formalization	X	X	X
K Distribution	X	X	X
K Application			
K Evolution			

X = relatively-good coverage by extant systems and practices

Coverage of Extant Systems and Practices. Nissen et al. [43] note the coverage of extant systems and practices across these two dimensions—knowledge management life cycle and reach—is patchy. At the enterprise level, for instance, numerous systems and practices are identified from the literature to support only three of the six life cycle phases: knowledge organization, knowledge formalization and knowledge distribution. These include, for example, systems such as knowledge maps, frequently asked question files and searchable “yellow pages” of personnel with varying areas of expertise, along with enterprise practices like discussing best practices, distributing lessons learned and arranging knowledge brokers to help match producers with consumers of knowledge.

In contrast, relatively few counterpart enterprise systems and practices are found to correspond with the other three phases: knowledge application, knowledge evolution and knowledge creation. These are limited, for example, to systems such as data mining and artificial intelligence (AI) from first principles,

along with enterprise practices like research and development, benchmarking and business intelligence. Interestingly, this pattern is quite similar across the other reach levels (e.g., organization, individual) as well. From this analysis, we find the process of knowledge management is unevenly supported by systems and practices. This uneven distribution is summarized in Table 2.

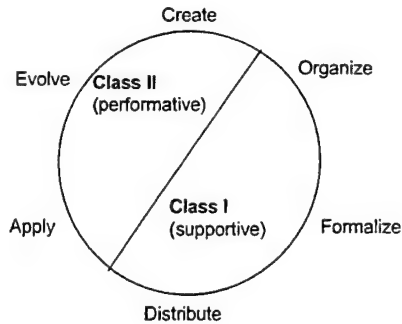


Figure 2 Knowledge Management Life Cycle
(Adapted from [43])

The uneven distribution is more readily discernable when the life cycle is presented as a circle, as opposed to a linear sequence of activities, as depicted in Figure 2. Notice the three well-covered activities from above—knowledge organization, formalization and distribution—are adjacent on the right-hand side of the cycle. These activities correspond with relatively-good support from extant information technologies and are grouped under the "Class I" heading in the figure. Such systems and practices are inherently supportive in nature; that is, this class of implementations and techniques to organize, formalize and distribute knowledge in the enterprise *support* people in the enterprise, whom in turn apply, evolve and create knowledge in the organization. Alternatively, the latter three, non-sharing activities are adjacent on the left-hand side of the cycle. But from Table 2, we see these activities do not correspond well with support from extant information technologies or management practices and are grouped under the "Class II" heading in the figure. Such systems are inherently performative in nature; that is, this class of implementations to apply, evolve and create knowledge in the enterprise *perform* knowledge-management activities, either in conjunction with or in lieu of people in the organization.

Integrated Knowledge Process and System Design. This prior research has led to development of a framework for integrating information system design with knowledge process design. The feature space of systems and technologies outlined above is further defined and constrained through this framework by a focus on process knowledge and contextual factors that impinge on the implementation of these systems in organizations. In the prior research (i.e., [43]), three complementary design methods are identified and integrated to address knowledge management. These methods draw from business process reengineering (BPR), expert systems (ES) development and information systems (IS) analysis and design. Each plays a key role in the progression from knowledge process design in the large, through knowledge analysis in the middle, and onto information system design in the detail. A key contribution of this prior work involves integration of these methods into a single, coherent, knowledge management design framework. This integrative framework is summarized as a four-step method in Table 3.

Table 3 Steps of Integrative Framework

Step	Activity
Step 1	Process analysis & (re)design
Step 2	Knowledge analysis & representation
Step 3	Contextual analysis
Step 4	IS analysis & design

In short, one first analyzes the processes associated with knowledge work performed in the enterprise. This step draws from common reengineering methods (e.g., [8, 23, 24]). Each process of interest must be understood and analyzed—and perhaps redesigned—to interpret the knowledge required for its effective performance. The next step is to identify and analyze the underlying knowledge itself. Central to the technique is the identification and analysis of critical success factors (i.e., the activities that must be performed effectively in order for the enterprise mission to be successful), which is useful to identify what knowledge is critical to process performance in a particular enterprise setting and context. This step further draws from textbook knowledge engineering methods employed for development of expert systems (cf. [25, 55, 59]), because such methods focus directly on knowledge—as opposed to data and information.

In the third stage of analysis, one assesses the contextual factors associated with the process of interest. Critical in this assessment is understanding the organization and the nature of knowledge underlying the task. Specifically, the role of organizational memory, organizational structure, incentives used to stimulate workers to contribute knowledge to systems and the distribution of canonical and non-canonical knowledge and practices through the enterprise exert strong constraints over the types of systems that can be employed for knowledge management. Finally, armed with results from these three levels of analysis (i.e., process, knowledge and context), one can then effectively analyze and design the information systems required to automate and support knowledge work in the process. Traditional IS methods (e.g., use of data flow diagrams, entity-relationship diagrams, object models, use cases) are employed to accomplish this, final stage of analysis.

Naval and Maritime Research Projects

The integrated framework from above has been used to guide several research projects focused explicitly on naval and maritime processes. We briefly summarize the key results from two such projects here: 1) carrier battlegroup theater transition process, and 2) maritime interdiction process. A number of other projects also address naval and maritime processes, such as the special warfare mission planning process [57], sailor/job-assignment process [21], library-research process [33], and information systems operations (ISO) curriculum access [63], but they are not quite as elucidating in terms of insight as those described below.

Carrier Battlegroup Theater Transition Process. This project seeks to decrease the time required for a carrier battlegroup to familiarize itself when arriving to a new theater of operations [49]. It focuses in particular on the quarterly battlegroup rotation that occurs in the Persian Gulf and identifies the intelligence process as one of the most critical in terms of knowledge flow. Specifically, intelligence personnel on board carriers and other battlegroup vessels require considerable time to develop an understanding of various actions and events in a new operational theater. Such an understanding pertains in particular to establishing and recognizing patterns and trends (e.g., flight paths of allied, neutral and enemy planes in the region), which directly impacts the battlegroup's ability to anticipate and respond quickly to a diversity of threats, indications and warnings that may occur in theater.

The key idea is to decrease the time required to develop such an understanding, and the project emphasizes knowledge flow between the departing battlegroup (i.e., the one that has been on station for three months) and its arriving counterpart. This knowledge flow is roughly operationalized in terms of action; that is, we measure the degree of knowledge flow in terms of how many days after arrival in theater are required before the performance and actions of the arriving battlegroup match the efficacy and appropriateness of those corresponding to the departing group. This is notionally depicted in Figure 3. The six, standard activities associated with the intelligence cycle are depicted as part of the battlegroup intelligence process as a horizontal directed graph. Subscripts associated with each activity indicate which instance of the process is being performed. An arrow of time is shown between the first and second instantiations to indicate they do not take place concurrently. The other directed graph, depicted vertically in the figure, suggests a *key aspect of knowledge management pertains to processes that run across various instantiations of the intelligence cycle* (e.g., as performed by different battlegroups, at different times).

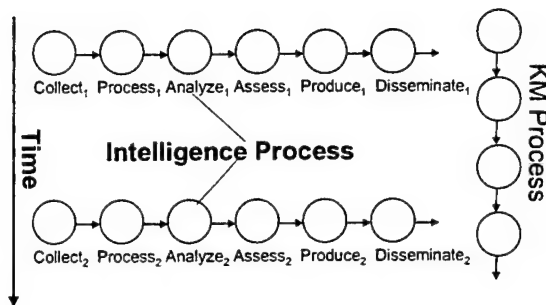


Figure 3 Battlegroup Intelligence Process Instances

(Adapted from [49])

Maritime Interdiction Process. The maritime interdiction process is associated with locating, stopping, boarding and inspecting suspicious vessels at sea [18]. Such actions are targeted for ships suspected of violating laws (e.g., against trafficking drugs, smuggling illegal aliens) and policy restrictions (e.g., enforcing embargoes, blockades), and the project emphasizes knowledge flow between personnel that are experienced with specific interdiction situations (e.g., drug seizures in the Caribbean Sea, Iraqi oil smuggled through the Persian Gulf) and their counterparts that are not. With certain duties that require considerable time and on-the-job experience to develop expertise, personnel are frequently transferred just as they achieve proficiency, and teams with personnel transferring in and out require time and practice to develop group-level coordination, trust and competence.

An important contribution from this project is the verification of and elaboration on the distinction, alluded to above, between *horizontal processes* and *vertical processes*. Briefly, horizontal processes correspond with those generally discussed in terms of business process reengineering, as they describe the key flow of activities required to perform organizational work and accomplish goals. Enforcing the No-Fly Zone, collecting battlegroup intelligence, interdicting Iraqi oil shipments, tracking Iranian aircraft activities, and navigating through littoral waters each represents an instance of a horizontal process. This term gets its name from the manner in which most process diagrams depict enterprise processes in terms of horizontal workflows.

In contrast, vertical processes pertain to performance *between instances* of horizontal processes [42]; that is, vertical processes enable, support and facilitate the level and consistency of performance across horizontal processes performed at different points in time and/or by different organizational units. Examples of such vertical processes include personnel selection and classification, distribution and assignment, after-action review, qualification, pre-deployment brief, education and training, post-deployment debrief, and IT support. Each of these vertical processes is useful to support diverse instances of the horizontal process. Unlike the horizontal, work-process flows, which pertain to the performance of work in the enterprise, the vertical, cross-process flows pertain to the process of knowledge management itself. Results from this study suggest *the key to knowledge flow lies in performance of such vertical processes*.

Current Knowledge-Flow Theory

One of the best-known theoretical treatments of knowledge flow stems from Nonaka [47] in the context of organizational learning. This work outlines two “dimensions” for knowledge: 1) epistemological, and 2) ontological. The epistemological dimension depicts a binary contrast between explicit and tacit knowledge. Explicit knowledge can be formalized through artifacts such as books, letters, manuals, standard operating procedures and instructions, whereas tacit knowledge pertains more to understanding and expertise contained within the minds of people. The ontological dimension depicts knowledge that is shared with others in groups or larger aggregations of people across the organization. Although his aggregation of

organizational units appears arbitrary, in the enterprise context, this could clearly apply to small teams, work groups, formal departments, divisions, business units, firms and even business alliances or networks. This coincides with our operationalization in terms of the dimension *reach* above.

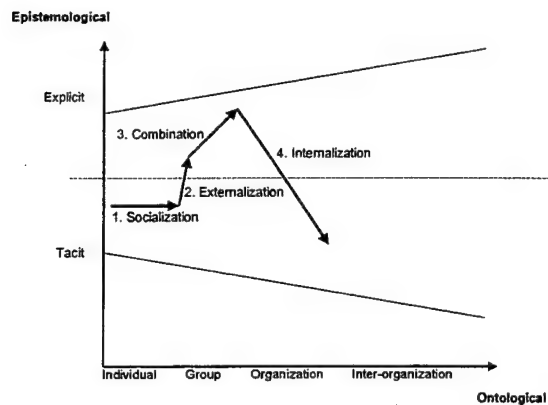


Figure 4 Nonaka Knowledge Flow Theory

(Adapted from [47])

As depicted in Figure 4, Nonaka views the interaction between these dimensions as the principal drivers of knowledge flow. This flow is roughly characterized through four steps. First, Nonaka asserts new knowledge is created only by individuals in the organization, and is necessarily tacit in nature. The first flow of knowledge is then theorized to occur through a process termed *socialization*, which denotes members of a team or “field” sharing experiences and perspectives. This first, socialization flow is noted as vector #1 in the figure and corresponds to tacit knowledge (i.e., along the epistemological dimension) flowing from the individual to the group level (i.e., along the ontological dimension). The second flow of knowledge (vector #2) is theorized to occur through a process termed *externalization*, which denotes the use of metaphors through dialog that leads to articulation of tacit knowledge and its subsequent formalization to make it concrete and explicit.

The third flow of knowledge (vector #3) is theorized to occur through a process termed *combination*, which denotes coordination between team members and other groups in the organization—along with documentation of existing knowledge—to combine new concepts from within teams through externalization with other, explicit knowledge in the organization. The fourth flow of knowledge (vector #4) is theorized to occur through a process termed *internalization*, which denotes diverse members in the organization applying the combined knowledge from above—often through trial and error—and in turn translating such knowledge into tacit form at the organization level.

Technical Approach

This technical approach section begins with theoretical extension to the research above. It then addresses the research questions (i.e., knowledge-flow theory development, very-large enterprise application, performance assessment) and summarizes three, interrelated technical tasks.

Theoretical Extension

Although Nonaka's dynamic theory above represents the current state of knowledge pertaining to the knowledge-flow phenomenon in the sciences and provides a useful foundation of concepts to describe such flows, it is limited in several respects and offers considerable room for extension and refinement. Here, we summarize the principal theoretical extensions—in the context of limitations and flaws associated with current theory—and outline the key insights from these extensions.

Limitations and Extensions. The first, principal limitation of current knowledge-flow theory pertains to the “dimensions” theorized above, as they only support discrete values or states (e.g., either tacit or explicit; aggregation at the individual, group, organization level). As suggested by Bloom [2], in contrast, one could argue instead that knowledge can take on many states—perhaps even fill a continuum—along the dimension characterized by tacit and explicit endpoints. Indeed, Bloom offers six states of knowledge that can be mapped to this same dimension and operationalizes each according to the kind of action that can be taken: 1) memorization, 2) comprehension, 3) application, 4) analysis, 5) synthesis, and 6) evaluation. We thus extend Nonaka’s model to accommodate these and other, additional states of knowledge and articulate them in terms of the actions they support.

Another, major flaw in Nonaka’s theory centers on the absence of a role for information technology in the process of enterprise knowledge flow. Referring back to his description of such flow from above, at every stage, *only people* are involved in the mechanics of knowledge creation and transfer. Yet the importance of technology (e.g., databases, networks, knowledge-based systems) is clear from the literary surveys by Nissen [39] and Nissen et al. [43], for example. We thus further extend Nonaka’s model to accommodate these and other, information-technology enablers of knowledge flow in the enterprise.

A third extension stems from our naval and maritime research projects, in which we explicitly differentiate between vertical processes and their horizontal-process counterparts, in terms of enabling knowledge flow. Such distinction and appreciation is simply absent from current theory, but it highlights an important, cross-process focus of knowledge flow. Indeed, noting the knowledge flow mechanisms discussed by Nonaka (e.g., socialization, externalization, combination) represent cross-process, vertical flows, this extension helps explain the mechanics associated with prior theory.

The fourth extension incorporates the knowledge management life cycle into Nonaka’s two-dimensional framework. Recall Nissen et al. [43] identify six stages through which knowledge flows as part of a knowledge management life cycle: 1) creation, 2) organization, 3) formalization, 4) distribution, 5) application, and 6) evolution. Incorporation of this, third dimension provides the basis for a richer model.

A further extension addresses the mechanics of knowledge flow. Although current theory includes concepts such as *socialization* and *externalization*, for instance, it fails to explain *how* knowledge can be transformed through such processes. This extension draws from the International Standards Organization (ISO) network model, which has seven layers involved with data communication (i.e., flow) between any two computer applications: 1) physical layer, 2) media-access layer, 3) network layer, 4) transport layer, 5) session layer, 6) application layer, and 7) presentation layer. According to this model—and others, such as the Internet TCP/IP Model—for one computer to communicate across the network with another, data must first be processed and flow downward through each layer in one computer—before transmission across the network—and then flow upward and be processed through each layer in another computer. As such, direct (e.g., application to application, presentation to presentation) data communication cannot occur. Therefore, critical design decisions pertaining to inter-computer dataflows concern the network architecture, these layers and the processing that is required at each level. Interestingly, software-agent communication languages (e.g., KQML) take a similar, layered approach to inter-agent communication and processing.

Analogously, for knowledge to flow between two agents in the enterprise—regardless of whether such agents represent people or machines—we conceptualize it to similarly pass through successive layers. First, the flow is from knowledge, through information, to data in one agent (e.g., Agent A). The data are then transmitted through some media (e.g., network, voice, handwritten page), and the flow in some other agent (e.g., Agent B) is reversed—from data, through information, to knowledge. This is depicted in Figure 5, which explicitly distinguishes between data, information and knowledge associated with the flow. This draws from the hierarchy of knowledge discussed above and provides powerful insight, as it suggests Nonaka’s concept of socialization, for instance, cannot involve direct transfer of knowledge between group members.

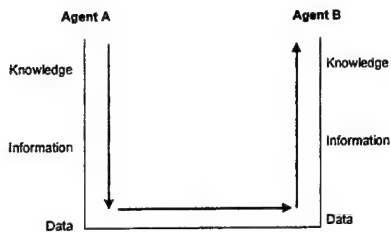


Figure 5 Layered Processing for Knowledge Flow

Key Insights. The key insights from these theoretical extensions are fourfold. First, machines (e.g., computers, expert systems, intelligent agents) can exchange knowledge as well as humans (e.g., people as individuals, in groups, in organizations). This represents a major extension to Nonaka's flow theory and explicitly recognizes the central role that information technology can play in the automation and support of knowledge flow. Second, knowledge does not flow directly between agents (human or machine); rather, only data flow across media between agents, and such data must be individually processed by each agent in order for information and knowledge to flow. This provides a conceptual bridge between the kind of social-science model conceptualized by Nonaka, for instance, and the engineering models (e.g., data-flow diagrams, object models, semantic networks) used for decades in information systems. And it begins to elucidate the mechanics involved with knowledge flow between agents (people and/or computers).

Third, to understand and describe knowledge flow, one must understand the *processing* used by various agents (again, human and/or machine) to transform data and information into actionable knowledge, and vice versa. There appears to be close correspondence between such agent processing and the kinds of vertical processes outlined above in terms of knowledge management. Fourth, the abstract and invisible concept *knowledge* can be operationalized into an observable and measurable construct *action*, which differentiates the knowledge of various agents based on their relative performance. This is analogous to the manner in which the Turing Test is used to determine the level of intelligence associated with computer systems, and the way computer chess programs are rated according the level of human players they are able to beat. These key insights form the basis of an extended theoretical model of knowledge flow, which is used to guide and inform the technical project tasks proposed below.

Technical Program of research Tasks

The three technical tasks include: 1) develop and refine a model of knowledge-flow theory; 2) develop a contingency model for knowledge system and process design; and 3) assess the performance effects of alternative knowledge systems and processes. As a note, the Principal Investigator has extensive experience using research methods appropriate for all three program of research tasks.

Task 1 – develop and refine a model of knowledge-flow theory. The theoretical extension from above provides a robust model for assessment through this first task. And toward this end, much of the conceptual work has been accomplished. For instance, drawing from our prior research and theoretical extension above, in Figure 6¹, we also note a few, notional knowledge-flow vectors to help illustrate the kinds of dynamics that can be captured and portrayed by this model. For instance, the simple, linear flow labeled "P&P" depicts the manner in which most enterprises inform and train employees through the use of

¹ Because Nonaka's terminology for the dimensions reflected in Figure 4 can lead to confusion (e.g., with respect to normal uses of the terms *epistemological* and *ontological*), we substitute the term *reach* for *ontological* and *explicitness* for *epistemological* in Figure 6. Notice we also expand the vertical axis using the six levels of knowledge/action taken from Bloom's work.

policies and procedures: explicit documents and guidelines that individuals in the organization are expected to memorize, refer and observe. As another instance, the cyclical flow of knowledge described by the Amalgamated Knowledge Management Life Cycle from above, depicted and labeled as “KMLC” in the figure, reflects a more-complex dynamic than its simple, linear counterpart. And as depicted, this latter flow delineates a cycle of knowledge creation, distribution and evolution within a workgroup, for example.

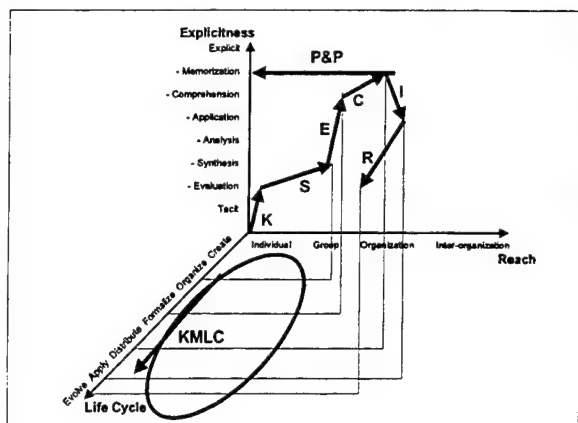


Figure 6 Extended Model with Knowledge Flows

Further, despite its shortcomings, Nonaka’s dynamic theory of knowledge flow can also be delineated in this space by the curvilinear vector sequence K-S-E-C-I. Referring back to the theoretical model above, these vectors correspond to the processes termed knowledge *creation*, *socialization*, *externalization*, *combination* and *internalization*, respectively. From this, our model entirely subsumes that proposed by Nonaka, and it reveals a somewhat complex dynamic as knowledge flows along the life cycle. For instance, the kinds of problems noted above with the mechanics of concepts such as *socialization* become apparent. Moreover, examination of this space suggests also including the “R” vector (*refinement*), which is not part of Nonaka’s theory but represents a key element of the empirically-derived, Amalgamated Model (e.g., key to knowledge evolution). Clearly, a great many other flows and patterns can be depicted in this manner.

Given this theoretical progress to date, what remains is to validate and refine the model through application to very-large enterprises in the world. A multiple case study method represents the most-appropriate approach to this task [64]. Such approach requires immersion into the environment of interest and can be very useful for identifying and interrelating important concepts, structures and relationships that exist, in addition to validating concepts and interactions proposed through the knowledge-flow model. In the case of this program of research, immersion into the Navy enterprise may take place in specific environments such as the carrier battlegroup, amphibious ready group and maritime aircraft patrol.

This immersion will also require consideration of the current technical approach and legacy systems involved with Navy knowledge management initiatives, for the knowledge developed through this program of research is intended to augment and enhance current efforts. Examples of organizations and initiatives of interest in this regard include the Navy CIO knowledge management initiatives [14], the ship-board initiatives of the Navy Network Centric Innovation Center [36], the Knowledge Home Port project [6], the knowledge management initiatives being launched at the Navy Personnel Research Studies and Technologies Office [52], the digital library project being performed at the Naval Postgraduate School [50] and other naval educational commands and the knowledge management efforts of Command Third Fleet. Preliminary contacts with these naval organizations have already been made regarding the performance of Task 1.

Task 2 – develop a contingency model for knowledge system and process design. Based on the theoretical work above in Task 1, various patterns of knowledge flows in the very-large enterprise need to be identified and understood, along with the kinds of knowledge process and system designs capable of their automation and support. This represents an analytical exercise that builds directly on the knowledge-flow theory to match various tools and practices with specific Navy processes (e.g., carrier battlegroup

theater transition, maritime aircraft patrol). The key is to apply knowledge-flow theory from above to the Navy and develop a means for matching the most-appropriate process and system designs for each specific knowledge flow pattern. This is analogous to long-practiced engineering techniques for matching various, well-understood components (e.g., resistors, capacitors, transistors) with desired patterns for electrical current flow (e.g., filtering, control, amplification) through circuit design.

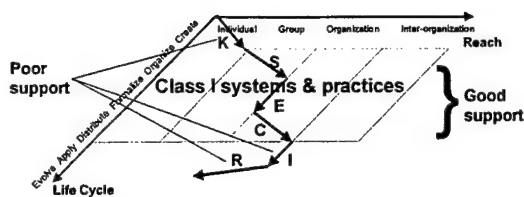


Figure 7 Extant IT Coverage

In fact, the technical background work, on which the proposed research builds, has already made progress along these lines. Recall, for instance, the analysis and results from prior research leading to Figure 2 in a previous section, which indicate relatively-good coverage of existing knowledge management tools and practices associated with the Class I (i.e., supportive) region of the knowledge management life cycle, but quite-poor coverage for the other, Class II (i.e., performative) region. Table 2 from above provides even greater detail, as it expands description of such coverage across the reach dimension (e.g., including the individual, group and organization), and we can further identify *specific* tools (e.g., e-mail, intranets, portals) and practices (e.g., compiling books of knowledge, establishing communities of practice, conducting workshops) corresponding to each cell in the table. Indeed, projecting the K-S-E-C-I-R vectors from above onto the two-dimensional plane (i.e., defined by *life cycle* and *reach*) in Figure 7, one can readily see the dichotomy between knowledge flows that are supported by extant systems and practices (e.g., socialization, externalization, combination) and their counterparts that lack such automation and support at present (e.g., creation, internalization, refinement). This task, therefore, has a solid foundation already, on which to build. It now requires extension to three dimensions and work to make it Navy-specific.

Informed by the results of Task 1 above and such prior research, this second task can be accomplished using the same kinds of knowledge-engineering methods (e.g., interviews, document analysis, use cases, decision tables and trees, rule chaining) that have been successful in the development of several knowledge-based systems (cf. [37, 38, 41]). In essence, the task amounts to developing rules, heuristics, cases, tables and other formalisms for matching the most-appropriate system and process interventions with the various patterns of diverse Navy knowledge flows. Indeed, the result of this task is intended to be sufficiently formal to provide a design document for building a corresponding decision support system (DSS) for automatically performing such matches. Implementation of such a system also represents a logical outcome of this research program.

Task 3 – assess the performance effects of alternative knowledge systems and processes. Given the lack of control one is able to impose on operational Fleet units, and difficulty recreating the richness of environments associated with Navy knowledge work (e.g., aboard a carrier at sea), assessing the performance of alternative knowledge system and process designs may best be accomplished through simulation. Simulation is increasingly applied to model and analyze complex phenomena in the physical sciences (e.g., electrical circuits, compressible fluid flow, energy and particle behavior), and its use is now widely accepted for studying phenomena in the social sciences (cf. [4, 30, 32, 38]). As with simulating any phenomenon, the key is to develop a model with good fidelity and to validate such model against the

behavior and performance of physical and/or social systems in real world (cf. [28, 46, 60, 61]). Once such a model has been constructed and validated, controlled experiments can be conducted without impacting the operational systems in the real world, yet the fidelity of the simulation model helps ensure the results are applicable and generalizable to the physical and/or social systems in the Navy.

This task can be approached through the same means employed to develop several, robust simulation models (cf. [37, 38, 41]) through prior research. The specific simulation tool itself remains to be determined, for the best choice will depend upon the nature of knowledge-flow and contingency models developed through the tasks above. But regardless of the specific tool selected, the end product of this third task is a validated and calibrated knowledge-flow simulation model that can be used to project the comparative, dynamic performance of various knowledge-work processes (e.g., using a variety of different information systems, vertical processes, other redesign interventions). Such a model can be used to assess the relative performance of competing process and system designs, and it can further support the kinds of cost/benefit tradeoff analyses that are common in most engineering disciplines. Informed by the resulting science of knowledge-flow theory, this work can place knowledge management well within the methods and tools commonly used for engineering work—a quantum shift from the current state of affairs.

Significance and Broader Impacts

The proposed program of research is very significant and has broader impacts than even the results of this specific investigation. We note above that knowledge is power and articulate how the Navy is now pursuing a strategy based on network-centric warfare. But it is necessary to understand knowledge-flow "physics" before one can expect to engineer useful systems and processes to enable and support such a strategy dependent on knowledge-flow. In this context, the program of research is significant in that new knowledge generated through this investigation can improve the efficacy of warfare. This offers potential for saving human life, resolving conflicts quickly and even avoiding conflicts altogether. The cost associated with current trial-and-error approaches to knowledge system and process design should also be greatly reduced, as this work may enable such systems and processes to be engineered systematically, as opposed to being crafted by trial and error and counting on serendipity for success.

Further, because this program of research focuses on central naval processes—such as the ones associated with carrier battlegroups, amphibious ready groups and maritime aircraft patrols—for study, all benefits accruing from this research are directly applicable to the Navy. But the program of research also has broader impacts. Indeed, there is no reason not to expect knowledge-flow theory to also benefit other military services (e.g., Air Force, Army) and allies (e.g., France, Germany, Great Britain) interested in pursuing network-centric warfare. And because knowledge work pervades every economic sector and type of organization, a wide diversity of other enterprises such as government agencies, businesses, non-profit organizations and other firms stand to benefit from knowledge-flow theory as well.

Additionally, development of knowledge-flow theory represents a scientific advancement that adds to our cumulative body of knowledge and literature. This work can make a significant impact on current thinking about knowledge management, providing a solid theoretical basis for argumentation, process and system design and resource allocation. Through results of this program of research, researchers will finally have a rich theoretical base to use for designing other studies, a base on which to build additional theory and understanding through application, extension, refinement and refutation. Indeed, this study directly supports current, important Navy research projects—including, for example, personnel selection and classification, distribution and assignment, knowledge system development, command and control, artificially-intelligent systems and decision aids—and the formal results can be extended to develop a DSS for designing systems and processes to automate and support specific Navy knowledge-flow patterns.

Finally, this program of research offers good potential to open a new line of scientific inquiry. And close integration of research with classroom instruction can support advances in education through principles, concepts and theoretical grounding associated with knowledge-flow theory. This does not exist at present in undergraduate or graduate curricula. Moreover, this work can help advance knowledge management from its current status—as something of a management fad—to a science worthy of academic inquiry and institutional funding. This represents a dramatic change from the environment today. The kinds of knowledge management projects and systems currently being pursued by the Navy are testimony to this fact.

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